ARMY RESEARCH LABORATORY

Performance Moderated Functions Server's (PMFserv) Military Utility: A Model and Discussion

by Daniel N. Cassenti

ARL-TR-4814 **May 2009**

NOTICES

Disclaimers

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5425

ARL-TR-4814 **May 2009**

Performance Moderated Functions Server's (PMFserv) Military Utility: A Model and Discussion

Daniel N. Cassenti
Human Research and Engineering Directorate, ARL

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)* May 2009	**2. REPORT TYPE** Final	**3. DATES COVERED (From - To)**
4. TITLE AND SUBTITLE Performance Moderated Functions Server's (PMFserv) Military Utility: A Model and Discussion		**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Daniel N. Cassenti		**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: AMSRD-ARL-HR-SE Aberdeen Proving Ground, MD 21005-5425		**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-TR-4814
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Performance Moderated Functions Server (PMFserv) modeling system is a structure designed to model the behavior of agents that are simulated based on established psychological principles. First, I detail the properties and principles of PMFserv, and then compare PMFserv to other prominent modeling. Based on these comparisons, PMFserv demonstrates a unique modeling skill set that may be of interest to U.S. Army research, and its limitations may be overcome through additional programming. I describe a model of a Robotics Noncommissioned Officer (NCO) as well as efforts to successfully add needed modeling functions to PMFserv, including greater use of stochastic processes, environment-evoked action, and thresholds. The model's results are presented including a critique of the type of results PMFserv offers, which are restricted to a list of actions. Finally, I discuss the model and consider the benefits and shortcoming of PMFserv regarding its applicability to military research problems. I conclude that PMFserv is limited by its inability to predict performance measures and lack of validation standards, though PMFserv may serve to provide insights into Army problems and solutions despite these limitations.

15. SUBJECT TERMS
modeling, robotics NCO, psychology

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Daniel N. Cassenti
Unclassified	Unclassified	Unclassified	UU	30	**19b. TELEPHONE NUMBER** (*Include area code*) (410) 278-5859

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

List of Tables

Acknowledgments

Foremost, I would like to thank Kevin Knight of the University of Pennsylvania for his persistent help and support of my project. Without his help, the programming in this report may not have come together. I would also like to thank Troy Kelley, Laurel Allender, Liz Bowman, Luci Salvi, and Don Headley for their thoughtful comments on earlier versions of this report. This effort was funded through internal U.S. Army Research Laboratory (ARL) 6.2 mission funds.

INTENTIONALLY LEFT BLANK.

1. Introduction

The Performance Moderator Functions Server (PMFserv) is a concept-modeling system for agents and was developed by the Barry Silverman Laboratory at the University of Pennsylvania (Silverman, 2006; Silverman, 2004). The concept-modeling nature of PMFserv emphasizes its intent to model agents in a simulated world realistically by using the conceptual underpinnings from a broad range of psychology research including psychobiological, cognitive, social, and clinical psychology.

The purpose behind this report was to investigate PMFserv for its utility in the U.S. Army human research mission, especially with regard to the behavior of new Army roles. The report begins with a description of PMFserv and the parts that compose it. Section 3 outlines a model of a Robotics Noncommissioned Officer (NCO) and presents the results of the model. The model serves as a test of how to extend PMFserv's capabilities for Army needs as opposed to a validation of its existing components. Three new capabilities are highlighted and achieved within the model: more widespread use of stochastic processes, environment-induced action, and the use of thresholds. The report concludes that PMFserv is useful only to Army applications that are informed by tabulations of behaviors. With a lack of traditional measures, such as accuracy or response time, performance-based conclusions must wait for updates of PMFserv before the modeling system will prove useful to more problems.

2. Overview of PMFserv

PMFserv incorporates four domains of psychological theories and models: psychobiological; personality, culture, and affect; social; and cognitive. The rationale offered for including multiple areas of psychological theory in PMFserv is that this will make the agents more realistic than models that include only one or two levels. The four areas represent four areas of psychology, including psychobiology, personality psychology, social psychology, and cognitive psychology.

The psychobiological modules of PMFserv are concerned with motivators and stressors, covering two modules: physiology and stress. The physiology module is a system of pumps and tanks comprising sleep and energy motivators. If the sleep tank is too low, this motivates the agent to sleep and if the energy tank is too low and nutrition is not available within the system, this motivates the agent to eat. The volumes in the sleep and energy tank are drawn through valves as the agent performs actions. Different actions take a user-set amount of volume. Figure 1 displays the physiology module.

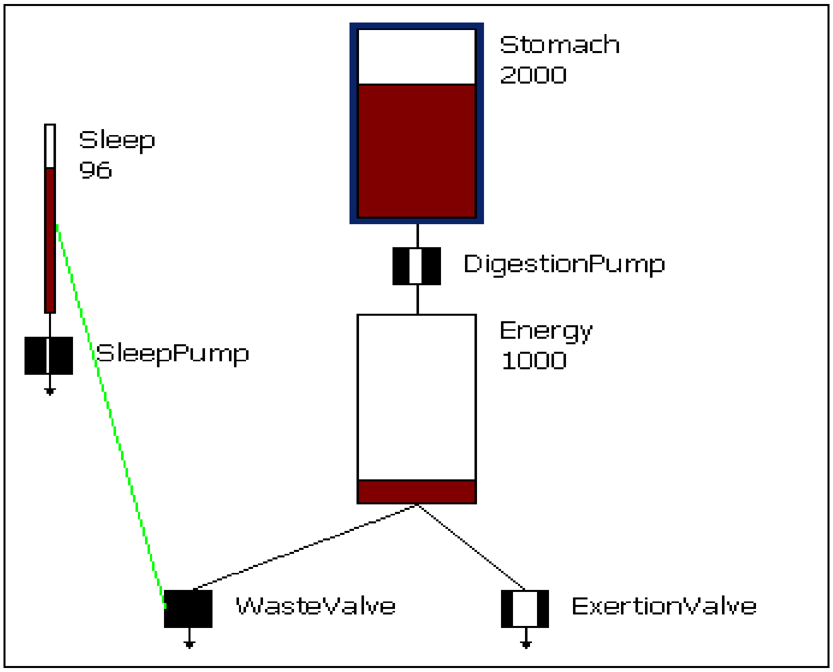


Figure 1. PMFserv's physiology module, in which sleep and energy tanks are depleted as actions are performed. If the energy tank becomes empty, then the stomach tank provides nutrition. If sleep or nutrition depletes to low levels, sleep and eating actions, respectively, become more important.

The second psychobiological module is the stress module. PMFserv uses three stress meters, event stress, effective fatigue, and time pressure, to calculate a coping style in its integrated stress meter. When the integrated stress meter reaches a specified level, it invokes a coping strategy that affects the actions that the agent will (or is able to) perform. From least to greatest stress, the agent responds with these coping strategies: unconflicted adherence (i.e., to current action), unconflicted change (i.e., to a new action), vigilance, defensive avoidance, and panic. Figure 2 displays the stress module.

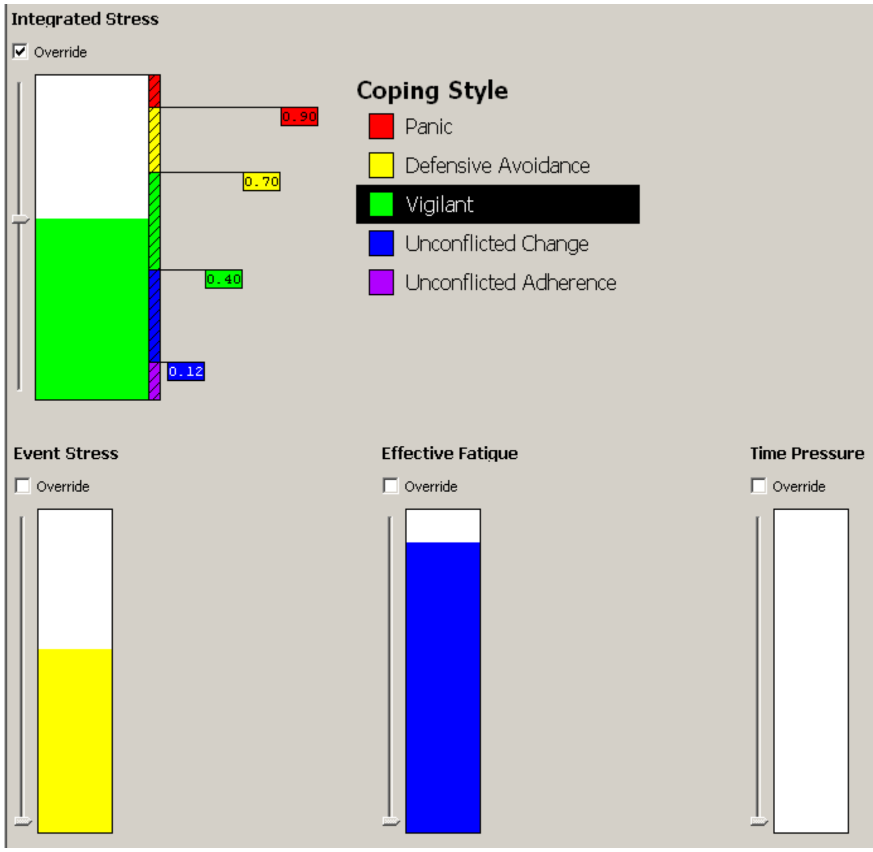


Figure 2. PMFserv's stress module, which uses three stress meters to calculate the amount of stress in the integrated stress meter. The amount of stress in the integrated stress meter increases or decreases as the three sub-meters increase or decrease, to varying degrees. As integrated stress increases, coping strategies are evoked bottom-up according to the legend in the upper-center.

Personality, culture, and affect is the level in PMFserv that encompasses values (attributable to personality and culture) and emotions (i.e., affect), two major factors in decision making. Values are reflected in the Goals, Standards, and Preferences Tree (GSP Tree). Each agent in a given model built in PMFserv has goals (i.e., results it would prefer to accomplish), standards (i.e., characteristics it would prefer to exhibit), and preferences (i.e., favored objects). For example, in the dog scenario developed in the Silverman laboratory, the dog has a goal to have a home, a standard of respecting the home, and a preference for the home itself. Each of these categories has a weight assigned to each of its elements and those weights always add to one across categories. Also, the modeler may add constituent parts to each of the category elements. For example, if a goal of the dog is to stay healthy then, as in the Silverman example, it will need to drink water, eat, and sleep. Each of the constituents of the elements must have weights that also add to one within the element.

The second component of personality, culture, and affect is emotion, which is measured in the emotion module. For each action that is performed, an agent advances towards or moves away from a goal or preference. The emotions are reflected on a scale with polar opposites. For actions the agent performs there are three emotional dichotomies: joy vs. distress, hope vs. fear, and liking vs. disliking. For actions performed by other agents there are six emotional dichotomies: pity vs. resentment, happiness vs. gloating, pride vs. shame, admiration vs. reproach, gratitude vs. anger, and gratification vs. remorse. Emotions affect both stress levels in the stress module and the expression of action.

The third domain of psychology in PMFserv is social. This level includes three modules: alignment, group knowledge, and psych social decision. Alignment characterizes the relationship between multiple agents in the same model. Alignment has two values: (1) valence, which is either negative (hostile), zero (neutral and the default), or positive (friendly); and (2) agency, which is how much the actions of the another agent affect the emotions of the agent.

Group knowledge is similar to alignment, except that it classifies the relationship of the agent to groups to which it may or may not belong. Group knowledge is more detailed in its emotional valence and includes specific emotional attributes such as helplessness and injustice. The actions of the group or group members will affect emotions based on their successes or failures and the emotional valence of the agent.

The psych social decision module is a storehouse of utility values. Background calculations attach utility (i.e., usefulness) values to actions of certain objects. These background calculations set the utility values so they may be viewed in this module and are not user-defined values.

The final domain of psychology in PMFserv is cognitive. The three functions best characterized as cognitive are perception, decision making, and memory. Memory does not reside in any particular module. Instead it is PMFserv's internal memory, which is a record of all variables and their associated values.

Perception is instantiated in the stressed perception module. Unlike models such as the Adaptive Control of Thought – Rational (ACT-R) cognitive modeling system (Anderson and Lebiere, 1998), PMFserv does not represent perceptual processes, but instead follows the principles of ecological perception (Gibson, 1966; 1979). According to Gibson (1979), each object in the field of view represents certain affordances or action that may be taken with or on the object. For example, floors afford walking, while ladders afford ascending or descending. In PMFserv, objects in the scenario afford certain actions, which restrict the overall set of goals that the agent may accomplish.

Decision making in PMFserv is drawn from a set of decision-making theories that use all the previously described values and elements to calculate the next action to be taken by an agent.

Example theories include prospect theory (Kahneman and Tversky, 1979) and decision theory (Keeney, 1982; Raiffa, 2002).

The previous discussion focused on *properties* of agents (summarized in table 1); the following discussion will focus on *objects*. As affordances, objects are the first determinants of action in PMFserv and as such have properties of their own (these properties also belong to agents, which are themselves objects that afford action for other agents). The first set of properties is contained in the state module and is a list of variables attached to the object. These variables may be used for performing functions in Python (i.e., the programming language that runs the PMFserv software, but may also be used by the programmer to write custom code) and may be either Boolean (i.e., true or false), number, or string variables.

Table 1. Summary of PMFserv agents' fields, modules, and parts of those modules.

Domain	**Module**	**Part 1**	**Part 2**	**Part 3**
Psychobiological	Physiology	Sleep	Energy	
	Stress	Event stress	Fatigue	Time pressure
Personality, culture, and affect	Values	Goals	Standards	Preferences
	Emotions	Joy vs. distress	Hope vs. fear	Like vs. dislike
Social	Alignment	Valence	Agency	—
	Group knowledge	Emotional valence	—	—
	Psych social decision	Utility values	—	—
Cognitive	Perception	Ability to view	Affordances	—
	Decision-making	Prospect theory	Decision theory	—

The next module is action bindings. This module stores the actions that the object affords. The list of actions is included in the actions field and those actions cause results that are stored in the result field. Each result may or may not have an action binding, which is a user-defined effect of the action on any variable among the objects and agents in the model.

The final module is perceptual types or P-Types. This module is where the modeler lists the properties of the object and also the actions and results included in the action bindings module. Each property has the option of perception rules and actions. Perception rules determine whether the object is perceivable and, if so, which agents can perceive it. The actions list contains all the actions that the object affords for agents, their results, and the ways in which the result would affect the agent's GSP Tree (i.e., take the agent closer or further from its goals, standards, and preferences).

In addition to objects and agents, there are also groups. Groups are conglomerations of agents that belong as members. Groups have the same three modules associated with objects (i.e., properties, action bindings, and perceptual types), but they also have an additional module labeled group identity.

The group identity module has three sections: properties, relationships, and ideas and intent. The properties section contains three fields. The first is memberships, which includes the agents that belong to the group, what the members' roles are, and an authority value. The salience field ascribes how noticeable an agent's exit from the group would be and how salient an agent's joining another group would be. The third field is the resource field, which contains the amount of political, economic, or security resources the group has from the start and how much it contains at present (the value changes as groups interact in negative or positive ways) within the simulation.

The relationships section characterizes the relationship of a given group to other groups. The relationship may be friendly, neutral, or hostile. Under the relationships section, the ideas and intent section contains two fields. First, the resource satisfaction field is a running count of how many resources each group has acquired, and second, the relative power field describes how much power or influence a group has in the simulation. Each of these fields defines its components by number quantities.

All of the components of PMFserv described and summarized in figure 3 (i.e., agents, objects, and groups) begin in the Object Library, a toolbox in PMFserv. A new PMFserv simulation starts with the creation and instantiation of a scenario. Once a scenario is begun, any of the elements from the Object Library may be included in the scenario. Multiple scenarios may populate the same Object Library, but only one is included in the simulation. Thus, the user may try a host of different combinations of elements and view the results.

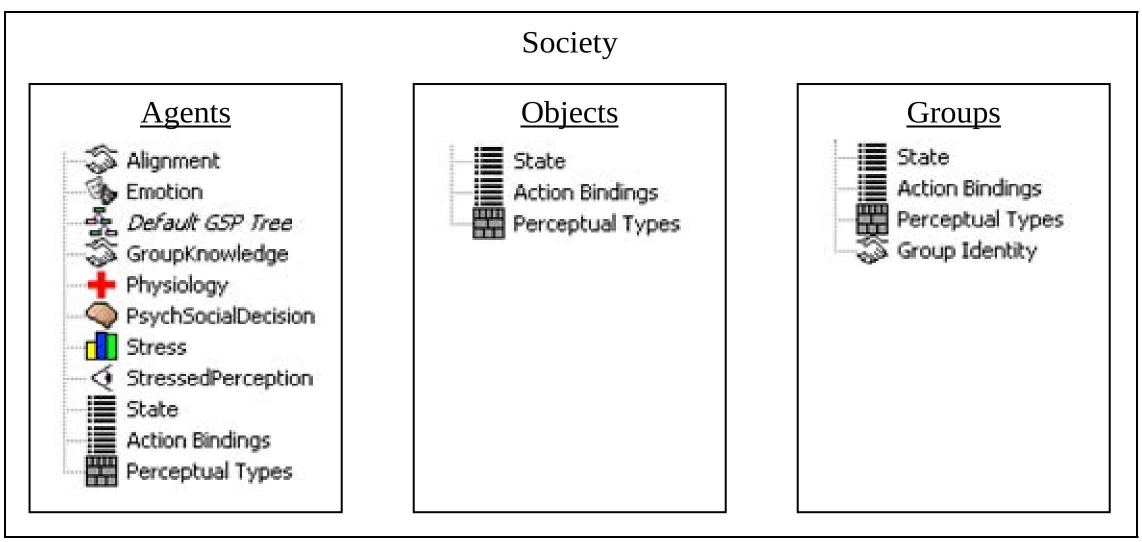


Figure 3. The components that compose a society in PMFserv.

Note: Agents may belong to groups. The icons and labels are copies from the PMFserv software (Silverman, 2006).

This discussion focuses on the results PMFserv produces. PMFserv produces two sets of results. First, a list of actions by agents is produced in the simulation field. This list of actions may then be sorted, classified, and summarized by proportions of actions of interest. This list of actions may be analyzed in a number of ways, including classifying some actions as errors and others as correct (i.e., accuracy) or by rank ordering actions by their desirability and rating the simulation's performance. Second, a PMFserv model may include variables that reflect changes as the simulation develops, which may also be of interest. These variable changes would reflect learning over time and could help to characterize how learning may unfold in a similar real world situation.

In the cognitive section described previously, I compared PMFserv to ACT-R, but there are also other approaches to modeling. For example, the Improved Performance Research Integration Tool (IMPRINT) network modeling system (Archer and Adkins, 1999) is a task-level modeling system. Instead of modeling individual mental processes like ACT-R, IMPRINT models whole tasks and augments the results based on higher-level concerns such as technology used, perceived mental workload, and environmental conditions.

Although IMPRINT is more like PMFserv than ACT-R, there are also fundamental differences between the two. The most important difference is that IMPRINT models tasks and mission success, whereas PMFserv models actions and the results are not definitive and qualitative, but a qualitative list of actions. IMPRINT is also not as focused on psychological theory as it is on physical properties (e.g., temperature).

The Command, Control, and Communications - Techniques for the Reliable Assessment of Concept Execution (C3TRACE) network modeling system (Kilduff, Swoboda, and Barnette, 2005) is much like IMPRINT except it focuses on communication and communication networks. C3TRACE takes on added significance with the Robotics NCO model outlined in section 3, which is based on communication. I will discuss C3TRACE in more detail in section 4.

3. Robotics NCO Model

3.1 Background

The primary purpose of this report is to expound on the applicability and usefulness of PMFserv for Army research goals. A model was built in PMFserv to evaluate the modeling system's usefulness in modeling an Army Military Occupational Specialty (MOS). The selected MOS that was modeled was that of a Robotics NCO. Although the Robotics NCO (Jensen, Tasoluk, Sanders, Marshall, 2005) is not yet a formal Army MOS, it likely will be incorporated into the official MOS list. An increasing demand and use of robots in Army tasks is making the Robotics

NCO necessary to carry out Army tasks. Specifically, the Robotics NCO would compile and coordinate information from robot operators and report this compiled information to a platoon leader for use in command and control.

The model was intended to use the functions of PMFserv described previously, but also to extend PMFserv's capabilities. PMFserv is different than other modeling systems such as ACT-R (Anderson and Lebiere, 1998) or the Symbols, Operators, and Rules (Soar) cognitive modeling system (Newell, 1990) in that it works on a highly symbolic (i.e., concepts and objects that drive the whole model) basis. Whereas modeling systems like ACT-R investigate how to implement model functions on a sub-symbolic and symbolic level (i.e., the mathematical equations and parameters that drive individual processes), PMFserv considers higher order principles, such as decision making, as opposed to declarative memory element activation.

One area that needs improvement is PMFserv's deficiency in stochastic outputs. Stochastic perturbations (i.e., noise) in ACT-R are responsible for errors in the activation of declarative memory that is not appropriate to the task. Also, different actions may be chosen when the situation is identical to a previous moment in the course of the model due to its stochastic nature. PMFserv has algorithms for choosing actions based on GSP Tree needs, but these actions are chosen based on what reflects highest need satisfaction. One goal of the Robotics NCO model was to extend PMFserv's capabilities by incorporating probabilistic environmental events, which in turn cause stochastic outputs.

Although introducing stochasticity in the Robotics NCO model involves varying the probability in environmental events rather than varying the way the Robotics NCO chooses actions, this approach adds a significant capability to PMFserv and is consistent with the Gibsonian (1979) view of perception. Many modeling systems (e.g., ACT-R and Soar) use perception of the environment to guide action. A PMFserv agent has objects in its environment that are perceivable, and these objects are available as options for any actions the agent needs to enact. However, in everyday tasks and particularly for a Robotics NCO who is waiting for information to be transmitted from robot operators, environmental actions occur and drive behavior. For example, if the phone is not ringing (i.e., to signal that a robot operator needs to send an oral message), then the Robotics NCO model should not attend. If the phone is ringing, then the Robotics NCO should be compelled to pick up the phone. In this example, the Robotics NCO does not choose when to answer the phone, but rather is compelled to answer when it rings and is compelled not to answer when it not ringing.

The inclusion of thresholds is another important step forward for PMServ. In ACT-R, thresholds compose a sub-symbolic process in which memory elements are not activated unless they pass a pre-determined activation strength. In the Robotics NCO model, thresholds were used to represent a precursor or release condition to action. For example, when information becomes strong enough and crosses the threshold, the Robotics NCO will report the information to the platoon leader.

Note that this model was only intended to be a working model and not to model any particular data. The model may, however, be used and adjusted to develop predicted actions of participants in the role of a Robotics NCO during empirical investigations.

The specific Robotics NCO task modeled is to receive input from robot operators who are investigating three sections of a path that a convoy will take the following day. The robot operators are tasked with reporting any potential dangers, such as signs of buried improvised explosive devices (IEDs). The operators are controlling the robots through teleoperation and have four ways of communicating information to the Robotics NCO: by phone, text message, image sending, or e-mailing global positioning system (GPS) coordinates. The Robotics NCO must accumulate these data and decide when to report a potentially hazardous route section to the platoon leader, who is coordinating the convoy path.

The Robotics NCO is an agent in the model (figure 4). The GSP Tree includes two goals, two preferences, and two standards. One set (one goal, one preference, and one standard) pertains to the Robotics NCO's need to be informed (i.e., by the robot operators) and the other pertains to the Robotics NCO's need to be informative (i.e., to the platoon leader). There was no representation in the Robotics NCO's GSP Tree of biological needs such as eating or sleeping. This omission was intended to keep the model as simple as possible and to leave it open for more development should PMFserv and this model be used in the future.

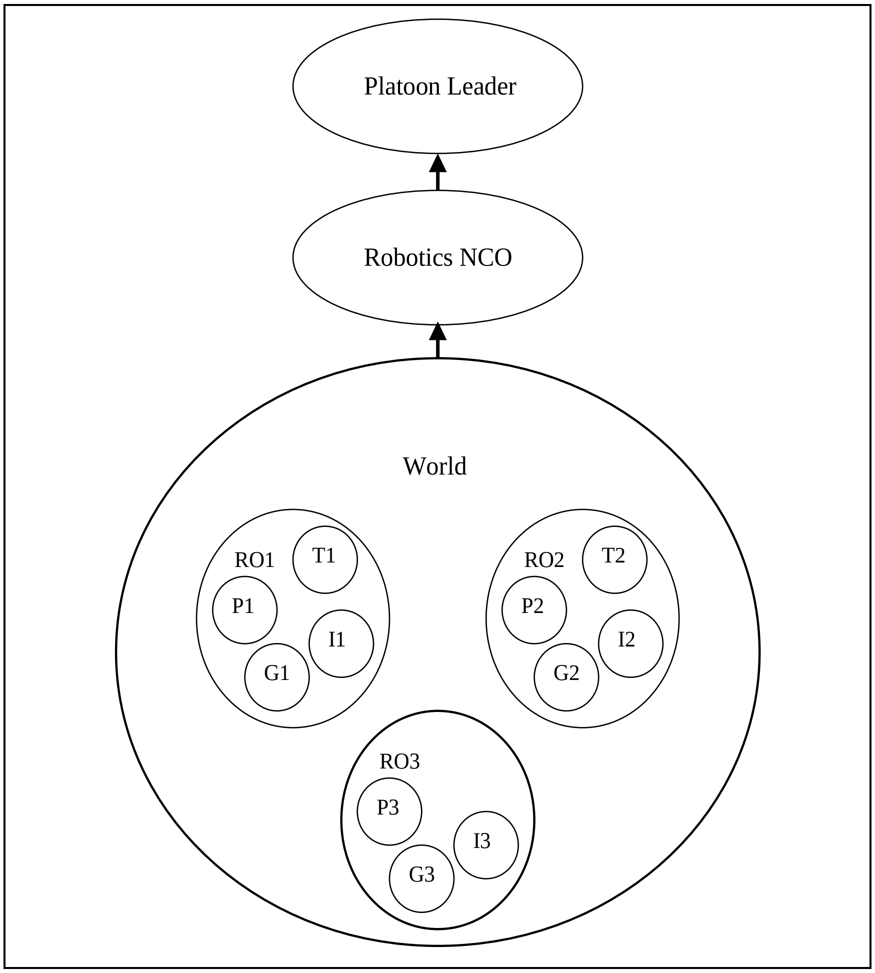


Figure 4. Representation of the Robotics NCO model.

Note: RO, T, P, G, and I stand for robot operator, text, phone, GPS, and image, respectively, with the number representing the robot operator in control of these devices. The bolded circles indicate that an information source is active. Arrows indicate single-direction flow of information.

The objects in the Robotics NCO's environment include one of each of the modes of operator communication for each of the three operators; therefore, there are three telephones, three text messaging consoles, three image consoles, and three GPS units labeled with a 1, 2, or 3 depending on which operator sent the information. Each means of communication also received one P-Type, which acted as a signal to the Robotics NCO that information was being transmitted. The P-Types were ringing for a phone, a chime for a text message, a flash for an image, and a beep for GPS coordinates.

Each object also had one action binding: each phone afforded answering, each text afforded reading, each image afforded looking, and each GPS afforded checking. All actions had one of two results—each with a 50% chance of occurring. The information was either important or unimportant and this factor was stochastic like the action results. If the information was important, then the Robotics NCO agent saw an increase in the informed needs of the GSP Tree.

Unimportant information only contributed information that the robot operator was still communicating, so these increased the GSP Tree only a fraction of the amount that important information did.

Every time that an object was perceived, the agent would perform the action afforded by the object. If the information conveyed was important, then a variable associated with the operator that provided the information would be incremented by one. All three of these variables were represented in the state module of the Platoon Leader, the final object in the model. The variables accumulated information points over time.

The Platoon Leader's P-Types include one threshold for each robot operator. That is, when the accumulated information for one of the three operators reaches five, the threshold becomes perceivable to the Robotics NCO and this triggers an action binding to report to the Platoon Leader. When that action is triggered, the variable resets to zero (i.e., the initial value) so that it may accumulate information once again.

The most difficult problem in composing this model was how to ensure that information objects only triggered some of the time. As the model has been described previously, each information object is only perceivable when it is activated. The model as described would not afford any action without a mechanism that activated the objects.

Knight (2008) suggested the creation of another agent called World whose sole function is to update the state of the objects in the environment. World had the same GSP Tree as the Robotics NCO. The one P-Type was called Update and would provide positive feedback to World on all needs in the GSP Tree.

An iteration of the update action triggered a resetting of all the objects. Functions were written for each object to make the probability of it being visible as 10%. In PMFserv, agents take turns producing an action. When World updated the environment, the agent followed with an action. When two objects were visible at once, the Robotics NCO would choose one. When no objects were visible, the Robotics NCO did nothing.

3.2 Results and Discussion of Robotics NCO Model

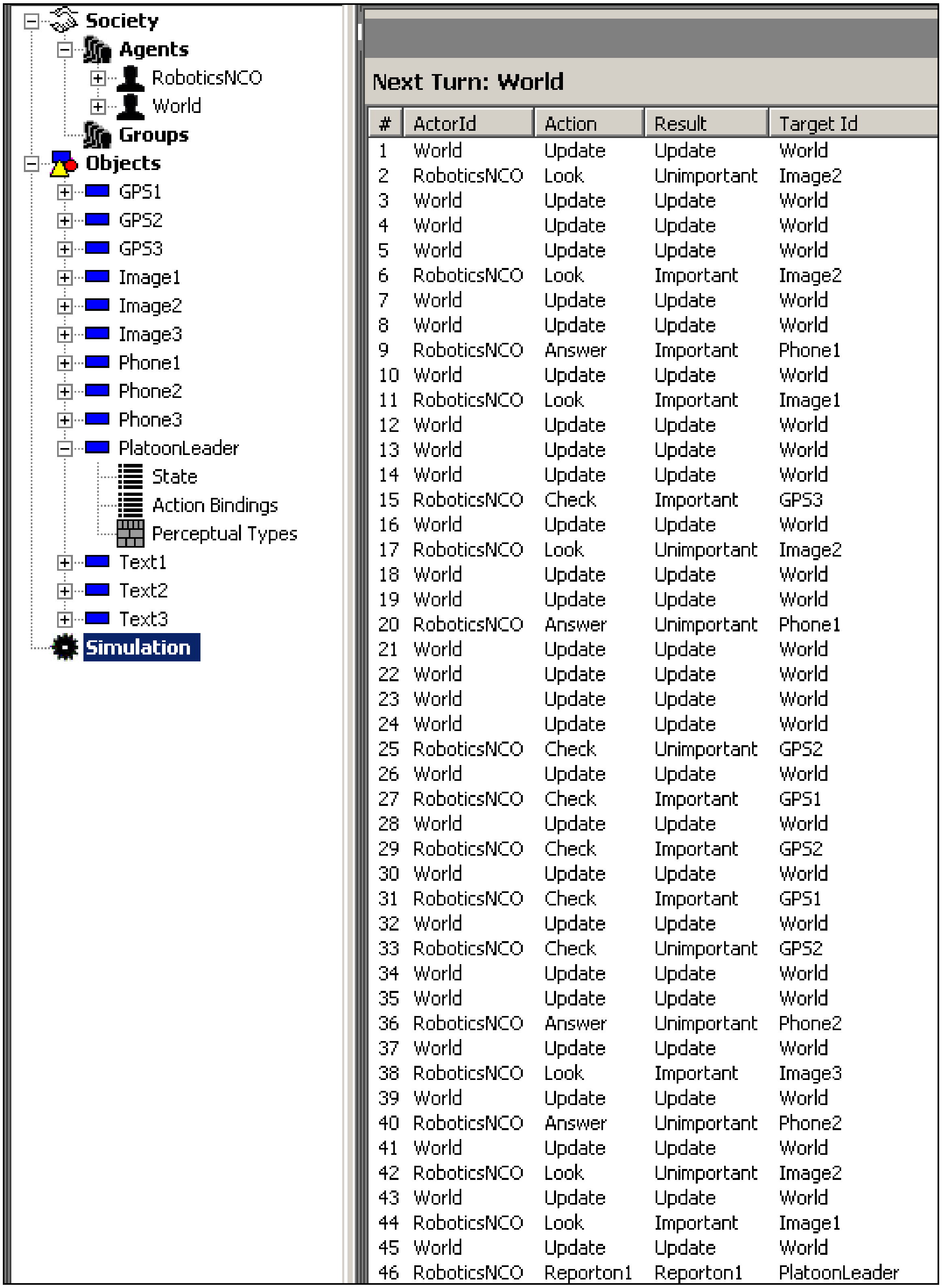
The Robotics NCO (figure 4 summarizes the model) model executed actions as intended. Furthermore, the model achieved three implementation goals including greater stochasticity, environmental signal for action, and the inclusion of thresholds. First (as described in section 3.1), probability was induced by implementing background Python code to provide a fixed 10% chance that an object could be perceived (i.e., when emitting a signal) when the World agent performed an update. This provided different environmental events rather than constantly available objects. Though probability does exist in PMFserv in the form of how likely given results will occur, this model introduced probability as to whether objects were available to afford action.

By linking probability to perception of an object, the actions of the agent are restricted by environmental signals. This opens PMFserv to signals from the environment to indicate when objects require attention. This advance moves PMFserv closer to more traditional cognitive models that have perception to indicate the presence or absence of stimuli.

Another feature implemented in PMFserv is the use of thresholds. ACT-R (Anderson and Lebiere, 1998) uses thresholds to determine whether certain memory elements may be available to ACT-R. In the Robotics NCO model, PMFserv uses quantity of information thresholds (i.e., the amount of important threat information communicated by robot operator) to determine when a report should be issued to the Platoon Leader. This serves a very important function in Army tasks, since military leaders may be overwhelmed with information if subordinates must report everything learned. Thresholds provide realistic and useful functionality to models that represent Army situations.

Another goal was to produce a model that could be altered to conform to new conditions or to model similar scenarios. Thresholds and values attached to incrementing functions (i.e., five and one, respectively) may be readily changed. For example, if it is determined that a GPS coordinate is the least useful information, then the increment value of 1 may be changed to 0.5. Similarly if one operator is determined to be less reliable than the others, its probability of an important result may be switched to something lower, like 20%.

Figure 5 displays a set of 46 ordered actions that the Robotics NCO and World agents performed before reporting to the Platoon Leader (made on behalf of Operator 1's path). This section displays the number of the action, actor, action taken, result, and the target object. In the figure, when five pieces of information deemed important finally accumulated, it caused the Robotics NCO to send a report to the Platoon Leader.



#	ActorId	Action	Result	Target Id
1	World	Update	Update	World
2	RoboticsNCO	Look	Unimportant	Image2
3	World	Update	Update	World
4	World	Update	Update	World
5	World	Update	Update	World
6	RoboticsNCO	Look	Important	Image2
7	World	Update	Update	World
8	World	Update	Update	World
9	RoboticsNCO	Answer	Important	Phone1
10	World	Update	Update	World
11	RoboticsNCO	Look	Important	Image1
12	World	Update	Update	World
13	World	Update	Update	World
14	World	Update	Update	World
15	RoboticsNCO	Check	Important	GPS3
16	World	Update	Update	World
17	RoboticsNCO	Look	Unimportant	Image2
18	World	Update	Update	World
19	World	Update	Update	World
20	RoboticsNCO	Answer	Unimportant	Phone1
21	World	Update	Update	World
22	World	Update	Update	World
23	World	Update	Update	World
24	World	Update	Update	World
25	RoboticsNCO	Check	Unimportant	GPS2
26	World	Update	Update	World
27	RoboticsNCO	Check	Important	GPS1
28	World	Update	Update	World
29	RoboticsNCO	Check	Important	GPS2
30	World	Update	Update	World
31	RoboticsNCO	Check	Important	GPS1
32	World	Update	Update	World
33	RoboticsNCO	Check	Unimportant	GPS2
34	World	Update	Update	World
35	World	Update	Update	World
36	RoboticsNCO	Answer	Unimportant	Phone2
37	World	Update	Update	World
38	RoboticsNCO	Look	Important	Image3
39	World	Update	Update	World
40	RoboticsNCO	Answer	Unimportant	Phone2
41	World	Update	Update	World
42	RoboticsNCO	Look	Unimportant	Image2
43	World	Update	Update	World
44	RoboticsNCO	Look	Important	Image1
45	World	Update	Update	World
46	RoboticsNCO	Reporton1	Reporton1	PlatoonLeader

Figure 5. An ordered set of 46 actions taken by the agents in Robotics NCO model.

In terms of matching data from the empirical studies, the ordered list of model results is only useful in matching the order of actions taken by participants in a study. Data summaries may also be made and be more informative in analyzing the match between empirical and model data. Table 2 displays the frequency of actions by the Robotics NCO and their results.

Table 2. Frequency of actions taken by the Robotics NCO agent (excluding the report made to the Platoon Leader) and results.

	Look at Image		**Check GPS**		**Answer Phone**		**Read Text**	
Operator	**Imp**	**Unimp**	**Imp**	**Unimp**	**Imp**	**Unimp**	**Imp**	**Unimp**
1	2	0	2	0	1	1	0	0
2	1	3	1	2	0	2	0	0
3	1	0	1	0	0	0	0	0

Note: Imp and Unimp stand for important and unimportant, respectively.

Table 2 illustrates a method of summarizing data. Although these values reveal very little about the Robotics NCO model (i.e., the table reflects largely scripted actions), this type of table may more fully represent action choices for agents that have multiple options for actions; whereas, in this model there were no action choices, only different frequencies of important and unimportant information being sent (the act of checking information was implemented whether the information was important or unimportant).

4. General Discussion

Aside from the Robotics NCO being a successful model in that it ran and gave clear results, it also represents a step forward in predicting the actions of a future Robotics NCO MOS. PMFserv provides a means of modeling an MOS that does not yet exist by representing the tasks and actions of a Robotics NCO. The model may, in part, help military decision makers decide whether to establish this new MOS based on a quantitative analysis.

The model-building process consisted of three steps: conceptualizing the model, building the model and scenario, and running the model, which generated output. Conceptualizing the model involved choosing the elements of PMFserv that best characterized the task of the Robotics NCO. The most representative focus was on the information sources. Not only is the concept of affordances the most representative quality of PMFserv, but the Robotics NCO acts as a channel for information gleaned from information sources, which afford certain actions.

Building the model was a process that blended system properties, such as the GSP Tree, but also blended some programming with Python code, including assigning probability to activation of information sources. Building the model was quick when using system properties, but slowed with programming. Running the model involved clicking on the model stepper until a representative sample of actions could be derived. This output was organized into a table of action frequencies.

As mentioned in the introduction to PMFserv, C3TRACE (Kilduff et al., 2005) is an alternative modeling system to model the Robotics NCO. C3TRACE is a task-based modeling system with a focus on communication and communication networks and the model depicts a Robotics NCO as part of a communication network.

Although utility may certainly be derived from a C3TRACE model of the Robotics NCO, this report was meant to focus on the workings of PMFserv, using the Robotics NCO as a method of exploring PMFserv. Another reason for modeling in PMFserv as opposed to C3TRACE is to initialize a model of the Robotics NCO rather than write the final model of the Robotics NCO. Future work may be devoted to exploring other aspects of PMFserv to more fully model the Robotics NCO. For example, the stress and physiology modules have not been used, though a Robotics NCO is like any other person and increased stress or needing food must affect their behavior. Another example is personality varies from person to person and different personality attributes may change the way a Robotics NCO acts. These functions are built into PMFserv, but not into C3TRACE.

This updated model would also require validation. As mentioned in the results section, a method of validating a PMFserv model would be to run experimental studies and compare the actions produced by the model to how participants in experiments perform the same task. The model could be altered by taking personality measures from the participant and matching those measures to PMFserv parameters that address the same factors. To assess the stress and physiological aspects, all actions would be recorded including snacking and number of bathroom breaks.

A more general question is: what does PMFserv as a modeling system offer to the U.S. Army? I will discuss both the strengths and the limitations of using PMFserv to study military situations in sections 4.1 and 4.2.

4.1 PMFserv's Strengths

PMFserv is a deep modeling system. Although (as previously discussed) PMFserv lacks some of the mechanisms of cognitive modeling systems, such as ACT-R and Soar, it also has more breadth than any other cognitive modeling system. A cognitive modeling system typically focuses solely on the cognitive aspects of behavior, but PMFserv covers cognitive aspects of psychology, as well as psychobiological, personality, and social aspects. One of ACT-R's stated goals is to represent "psychological reality" (Anderson and Lebiere, pp. 13) and although there are movements for ACT-R towards other aspects of psychology (e.g., stress [Ritter, Reifers, Klein, and Schoelles, 2006] and emotion [Belavkin, Ritter, and Elliman, 1999]), PMFserv arguably has greater psychological realism.

Another strength of PMFserv is its capacity to study a new MOS (though PMFserv does not have MOS information built into the system). The MOS system covers almost 500 specialties. Given the large number of specialties and the constantly changing nature of Army tasks, new and updated MOS databases are bound to occur. If these new or altered specialties have definable roles and tasks, then PMFserv may represent these roles and tasks and reveal the types of behaviors that may be expected from personnel within the MOS. This information may help military decision makers determine whether the MOS is a useful addition.

With the breadth of PMFserv comes another benefit for Army research goals. PMFserv attempts to model a plethora of psychological theories within multiple disciplines. This feature may result in emergent behaviors that cannot be predicted by any other psychological modeling system. For example, though the Robotics NCO model as implemented did not factor in hunger and sleep needs, a slight modification would show that, at some point, the Robotics NCO would fall asleep or seek food while ignoring the information from operators. This type of behavior is generally not predicted in other modeling systems (although IMPRINT is one exception).

The final strength discussed here is the ability of PMFserv to generate new scenarios quickly. PMFserv contains a library of objects, agents, and groups. This library can be mixed and matched depending on the specific environment of an agent. The user may also make copies of scenarios and these copies may be opened and changed without altering the original scenario. This feature allows multiple scenario creation without complete reconstruction. The Army has an infinite number of scenarios that may occur. This type of scenario generation will provide quick model-behavior generation and allow decision makers to optimize what equipment and other artifacts should be provided to personnel.

4.2 PMFserv's Limitations

For all of the strengths of PMFserv, there are also some limitations. First, PMFserv models include many user-entered parameters. These parameters are determined by the modeler and may or may not represent the real world. For example, the Robotics NCO had a threshold of five before reporting to the Platoon Leader. For different individuals, this may not necessarily be true (e.g., a more cautious individual may use a smaller threshold). Other examples of possible inaccurate user-entered information includes GSP Tree motivation values, the affordances of object (i.e., some individuals may find objects to be useful in more ways than others), and stress levels. Not only are these difficult to estimate, they are also difficult to confirm. For example, there is no method for determining how motivating a certain goal is compared to other goals for a given individual.

PMFserv also has a deficiency in the results of models. An ordered list of behaviors or even a summary of behaviors exhibited is not generally useful in determining how well an agent performs in a given situation. Army human research often focuses on performance measures, such as accuracy and response time. The Army is likely to be more concerned with success and failure than on a list or table of behaviors.

PMFserv does have a mechanism for modeling success and failure of actions, but the probability of success or failure is set by the user in the results section of the action bindings module. Just like values in the GSP Tree, this probability is based on estimation rather than an empirically based value.

Accuracy is not the only method of judging performance. Response time indicates how long a task took to accomplish—the lower the response time, the more efficient the task performance. PMFserv has no mechanism for judging response time. Instead PMFserv uses a standard cycle time and it takes one cycle to perform any action, no matter how difficult.

The final limitation of PMFserv modeling is that unlike many cognitive modeling systems, there is no mechanism for learning. Learning is a natural part of human psychology, but in PMFserv values stay the same and no adjustment in behaviors occurs depending on success or failure.

5. Conclusions

PMFserv is a very complex and broad model of psychological processing. It incorporates several disciplines of psychology and has the propensity to model a large variety of agents, tasks, and scenarios. A successful model was constructed of a proposed new type of Army specialty (i.e., the Robotics NCO), which extended the capabilities of PMFserv to probabilistic environmental events, environment-induced actions, and thresholds.

PMFserv may need more work before it becomes useful to the Army. The issue surrounds two problems—results and validation. The results are lists and tables or behaviors and the Army is more interested in performance-based measures, such as accuracy and response time. In addition, the parameters that construct models need more validation. Parameters that are entered should be based on verifiable empirical findings. Until validation techniques have been implemented, PMFserv is an incomplete system.

Despite its limitations, PMFserv may support Army human research goals as currently composed. Though performance measures are desirable, emergent behaviors and matching model-produced behaviors to empirically grounded behaviors may provide insights and predictions for Army tasks.

6. References

Anderson, J. A.; Lebiere, C. *The Atomic Components of Thought*; Erlbaum: Mahwah, NJ, 1998.

Archer, S.; Adkins, R. *IMPRINT User's Guide*; prepared for the U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 1999.

Gibson, J. J. *The Senses Considered as Perceptual Systems*; Houghton Mifflin: Boston, 1966.

Gibson, J. J. *The Ecological Approach to Perception*; Houghton Mifflin: Boston, 1979.

Kahneman, D.; Tversky, A. Prospect Theory: An Analysis of Decision Under Risk. *Econometrica, XLVII* **1979**, 263–291.

Keeney, R. L. Decision Analysis: An Overview. *Operations Research* **1982**, *30*, 803–838.

Kilduff, P. W.; Swoboda, J. C.; Barnette, B. D. *Command, Control, and Communications: Techniques for the Reliable Assessment of Concept Execution (C3TRACE) Modeling Environment: The Tool*; ARL-MR-0617; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2005.

Knight, K. Personal communication. 24 April 2008.

Newell, A. *Unified Theories of Cognition*. Harvard University Press: Cambridge, MA, 1990.

Raiffa, H. Decision Analysis: A Personal Account of How It Got Started and Evolved. *Operations Research* **2002**, *50*, 179–185.

Ritter, F. E.; Reifers, A. L.; Klein, A. C.; Schoelles, M. J. Lessons Fordefining Theories of Stress. *Integrated Models of Cognitive Systems*; Gray W., Ed.; Oxford University Press: New York, NY, 2006.

Silverman, B. G. Toward Realism in Human Performance Simulation. *The Science and Simulation of Human Performance*; Ness, J. W.; Ritzer, D. R.; Tepe V., Eds.; Elsevier: New York, NY, 2004; pp 469–498.

Silverman, B. G. PMFserv (Version 2.1.0) [Computer Software]. *Edutainiacs: LLC* **2006**, Philadelphia, PA.

List of Symbols, Abbreviations, and Acronyms

ARL	U.S. Army Research Laboratory
ACT-R	Adaptive Control of Thought – Rational
C3TRACE	Command, Control, and Communications: Techniques for the Reliable Assessment of Concept Execution
GPS	global positioning system
GSP Tree	Goal, Standards, and Preferences Tree
PMFserv	Performance Modulated Function Server
IEDs	improvised explosive devices
IMPRINT	Improved Performance Research Integration Tool
MOS	Military Occupational Specialty classification of Army roles
NCO	Noncommissioned Officer
P-Types	perceptual types
Soar	Symbols, Operators, and Rules

NO. OF COPIES	ORGANIZATION
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR ML J MARTIN MYER CENTER RM 2D311 FT MONMOUTH NJ 07703-5601
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MZ A DAVISON 320 MANSCEN LOOP STE 115 FT LEONARD WOOD MO 65473
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MD T DAVIS BLDG 5400 RM C242 REDSTONE ARSENAL AL 35898-7290
1	COMMANDANT USAADASCH ATSA CD AMSRD ARL HR ME DR HAWLEY 5800 CARTER RD FT BLISS TX 79916-3802
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MM DR V J RICE BLDG 4011 RM 217 1750 GREELEY RD FT SAM HOUSTON TX 78234-5002
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MG R SPINE BLDG 333 PICATINNY ARSENAL NJ 07806-5000
1	ARMY RSCH LABORATORY - HRED ARMC FIELD ELEMENT AMSRD ARL HR MH C BURNS THIRD AVE BLDG 1467B RM 336 FT KNOX KY 40121
1	ARMY RSCH LABORATORY - HRED AWC FIELD ELEMENT AMSRD ARL HR MJ D DURBIN BLDG 4506 (DCD) RM 107 FT RUCKER AL 36362-5000
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MK MR J REINHART 10125 KINGMAN RD FT BELVOIR VA 22060-5828
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MY M BARNES 2520 HEALY AVE STE 1172 BLDG 51005 FT HUACHUCA AZ 85613-7069

NO. OF COPIES	ORGANIZATION
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MP D UNGVARSKY POPE HALL BLDG 4709 BCBL 806 HARRISON DR FT LEAVENWORTH KS 66027-2302
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MJF J HANSBERGER JFCOM JOINT EXPERIMENTATION J9 JOINT FUTURES LAB 115 LAKEVIEW PKWY STE B SUFFOLK VA 23435
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MQ M R FLETCHER NATICK SOLDIER CTR AMSRD NSC WS E BLDG 3 RM 343 NATICK MA 01760-5020
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MT J CHEN 12423 RESEARCH PKWY ORLANDO FL 32826
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MT C KORTENHAUS 12350 RESEARCH PKWY ORLANDO FL 32826
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MS C MANASCO SIGNAL TOWERS BLDG 29808A RM 303 FT GORDON GA 30905-5233
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MU 6501 E 11 MILE RD MS 284 BLDG 200A 2ND FL RM 2104 WARREN MI 48397-5000
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MF C HERNANDEZ 2421 NW AUSTIN RD STE 220 FT SILL OK 73503-9042
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MV S MIDDLEBROOKS 91012 STATION AVE RM 348 FT HOOD TX 76544-5073

NO. OF COPIES	ORGANIZATION
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MN R SPENCER DCSFDI HF HQ USASOC BLDG E2929 FT BRAGG NC 28310-5000
1	ARMY RSCH LABORATORY - HRED AMSRD ARL HR MW E REDDEN BLDG 4 ROOM 332 FT BENNING GA 31905-5400
1 (CD only)	ARMY G1 DAPE MR B KNAPP 300 ARMY PENTAGON RM 2C489 WASHINGTON DC 20310-0300
1 (PDF only)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FORT BELVOIR VA 22060-6218
1	DIRECTOR US ARMY RESEARCH LAB IMNE ALC HRR 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB AMSRD ARL CI OK TL 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB AMSRD ARL CI OK PE 2800 POWDER MILL RD ADELPHI MD 20783-1197

NO. OF COPIES	ORGANIZATION
	ABERDEEN PROVING GROUND
7	DIR USARL AMSRD ARL CI OK TP S FOPPIANO AMSRD ARL HR P FEDELE T LETOWSKI AMSRD ARL HR MD D HARRAH AMSRD ARL HR MR F PARAGALLO AMSRD ARL HR SD B AMREIN AMSRD ARL CI OK TP (BLDG 4600)

TOTAL: 33 (1 ELEC, 1 CD, 31 HCs)

INTENTIONALLY LEFT BLANK.